isolation achieved by antenna alignment (about 40 dB), we found that for all but one radar type, the DSRC system and existing C-band radars should be compatible at distances of 1 km, (or less) with the exceptional case requiring a 2-km separation.

It is expected that for most radar installations, coordination with DSRC systems operations will allow the required isolation resulting from frequency offset and antenna alignment to be achieved. Possible modifications that can be used to enhance compatibility in the event that the required isolation cannot otherwise be achieved are given below.

4.2 Recommendations for Enhanced DSRC Electromagnetic Compatibility

Taking into account the results of the DSRC tests and data analysis, we make the following recommendations for design modifications to the DSRC to improve electromagnetic compatibility with both current and future radiolocation operations in the 5-GHz portion of the spectrum:

1. The electromagnetic compatibility between DSRC stations and radar stations within the 5850- to 5925-MHz spectrum band can be enhanced through the incorporation of modified DSRC data-encoding schemes.

It was noted during the course of the tests and measurements that deleterious interference effects were more pronounced when the duty cycle was increased, and that pulse repetition rate was particularly important as an interference factor. This dependence implies that significantly improved DSRC performance in the presence of radar interference may be achievable through the use of shorter DSRC data packets, and possibly through the use of forward error correction (FEC) in the DSRC coding scheme. Shorter DSRC data packets would reduce the probability of the loss of data bits due to simultaneous occurrence with radar pulses. We believe that shorter data packets would have the same effect as lower radar duty cycle. FEC should be useful in recovering individual bits that might be lost due to radar pulse interference as well, but the effectiveness of both of these approaches is beyond the scope of this report, and need to be studied separately.

2. Even with the suggested changes to the DSRC system protocol, there remains one possible electromagnetic compatibility problem that cannot be solved by modifying the DSRC design: the case in which a radar is co-channel to the DSRC receiver frequency, and the radar signal is received at such a high amplitude that front-end overload occurs in the DSRC beacon receiver front-end. This may happen if a DSRC station is within close proximity to a very high-power radar, such as an FPS-16. In such a case, electromagnetic compatibility can only be achieved by installing a notch filter in the DSRC front-end at the radar frequency (or a band-reject filter that is effective across the range of selectable radar frequencies), or else by tuning the radar below 5850 MHz (where the interference will be mitigated by the DSRC 5250- to 5850-MHz band-reject filter). At such locations, long-term coordination will be required to ensure that the DSRC and radar frequencies do not coincide. Locations in the United States where we anticipate that such coordination may be required are

Wallops Island, Patuxent Naval Air Test Center, Cape Canaveral Air Force Station, Eglin Air Force Base, White Sands Missile Range, Edwards Air Force Base, China Lake Naval Weapons Center, Vandenburg Air Force Base, and Point Mugu.

4.3 Recommended Additional Analysis

Our measurements indicate that there is a strong likelihood that DSRC system performance in the presence of radar interference can be substantially improved through the use of data encoding schemes. The tests and analysis that were performed were not adequate to make that determination definitively. Further analysis needs to be performed to determine, quantitatively, to what extent DSRC electromagnetic compatibility can be improved through the use of such a design modification, and indeed what data encoding modifications would be most effective. Therefore, we recommend that additional resources be devoted to determining engineering changes in DSRC data transfer protocols that would effectively mitigate co-channel, pulsed interference from radar stations.

5. REFERENCES

[1] F.H. Sanders and V.S. Lawrence, "Broadband spectrum survey at Denver, Colorado," NTIA Report 95-321, Sep. 1995.

[2] F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at San Diego, California," NTIA Report 97-334, Dec. 1995.

[3] F.H. Sanders, R.L. Hinkle, and B.J. Ramsey, "Analysis of electromagnetic compatibility between radar stations and 4 GHz fixed-satellite earth stations," NTIA Report 94-313, Jul. 1994.

[4] R.J. Matheson, J.D. Smiley, G.D. Falcon, and V.S. Lawrence, "Output tube emission characteristics of operational radars," NTIA Report 82-92, Jan. 1992.

[5] European Committee for Standardization (CEN), "Dedicated short-range communications physical layer," Predraft Standard, Dec. 1995.

[6] G.A. Hufford, A.G. Longley, and W.A. Kissick, "A guide to the use of the ITS Irregular Terrain Model in the area prediction mode," NTIA Report 82-100, Apr. 1982.

APPENDIX A: MEASURED WAIT TIME STATISTICS

The measured wait time statistics in the presence of interference are presented in this appendix. These data are presented in Figures A-1 through A-30 in the form of both histograms and cumulative distribution functions for the interference pulse parameters given in Table 1 of this report. In each case, statistics were obtained at several levels of peak RF interference power. For each pulse parameter set, statistics were typically measured at three interference power levels: the lowest power level where the wait time obviously starts to increase relative to an interference-free channel, and two additional measurements at 10 and 20 dB above this minimum. The percentage of trials that exceed a desired wait time can be evaluated directly from the cumulative distribution plots.

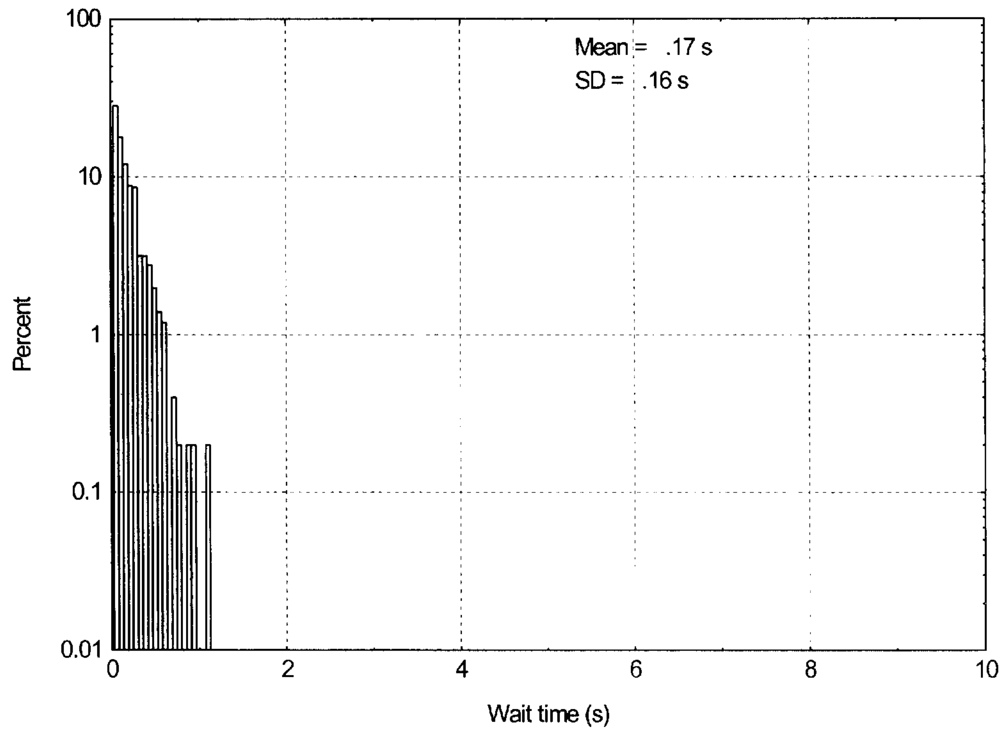

Figure A-1. Wait time histogram, interference pulse parameters: pulse width = 1 µs, pulse period = 1 ms, peak RF power = −68 dBm.

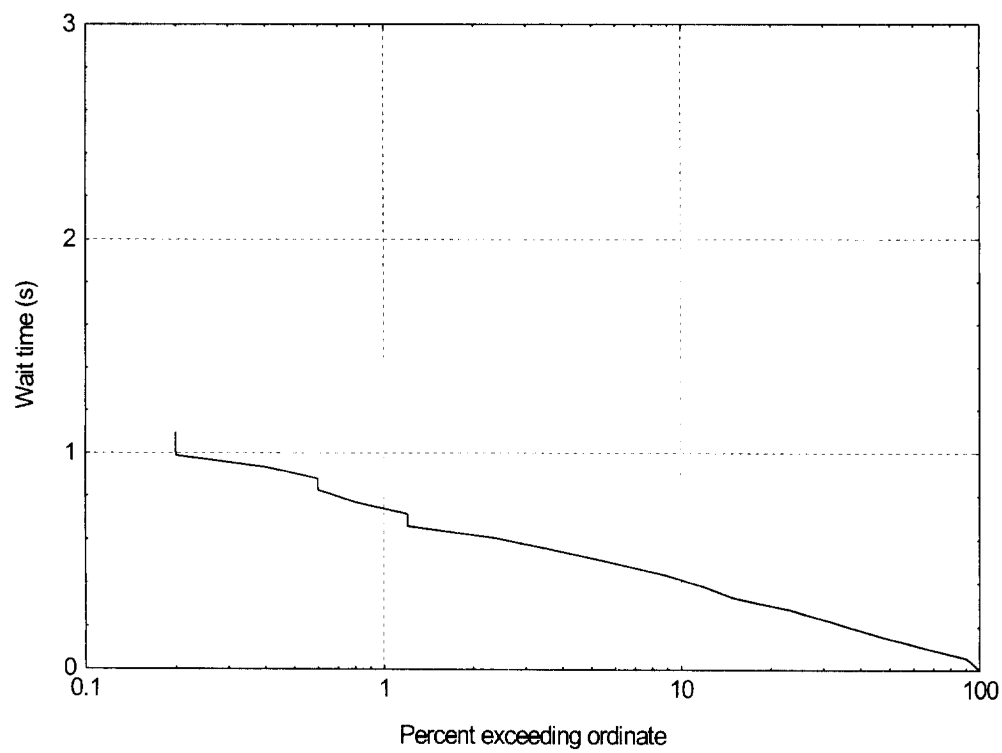

Figure A-2. Wait time cumulative distribution, pulse parameters: pulse width = 1 µs, pulse period = 1 ms, peak RF power = −68 dBm.

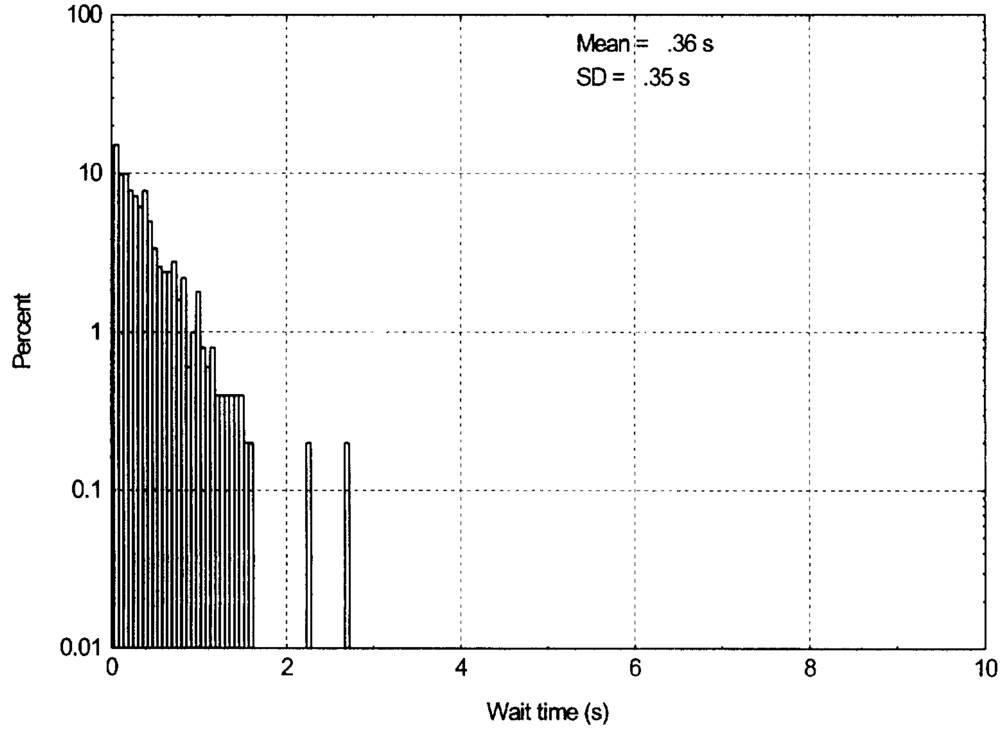

Figure A-3. Wait time histogram, interference pulse parameters: pulse width = 1 μs, pulse period = 1 ms, peak RF power = −58 dBm.

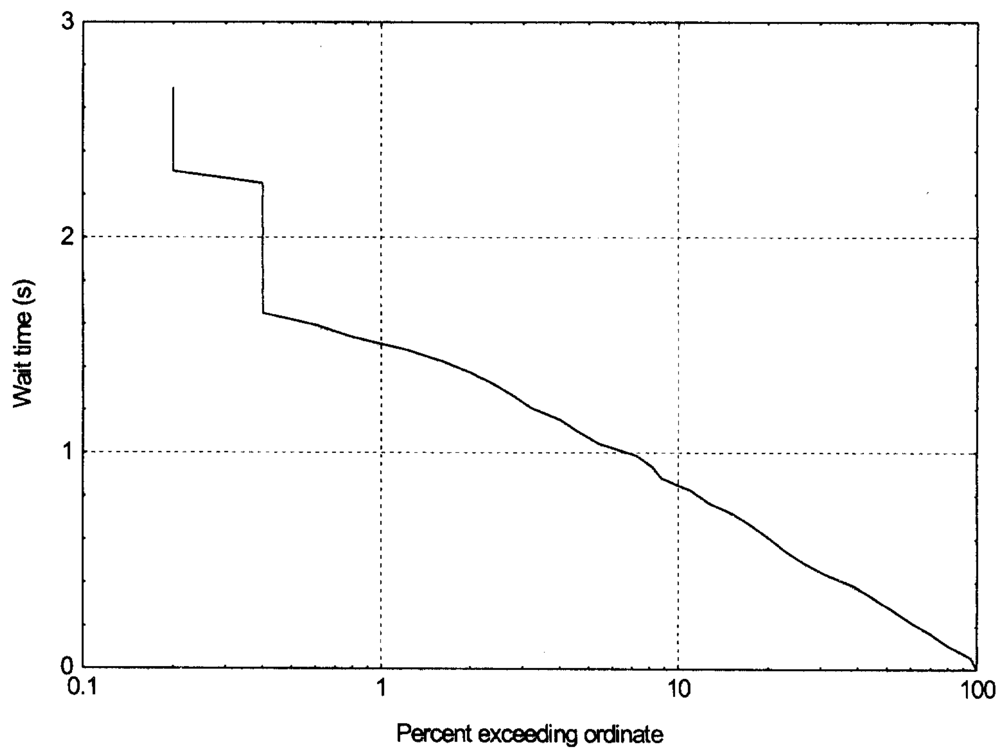

Figure A-4. Wait time cumulative distribution, pulse parameters: pulse width = 1 μs, pulse period = 1 ms, peak RF power = −58 dBm.

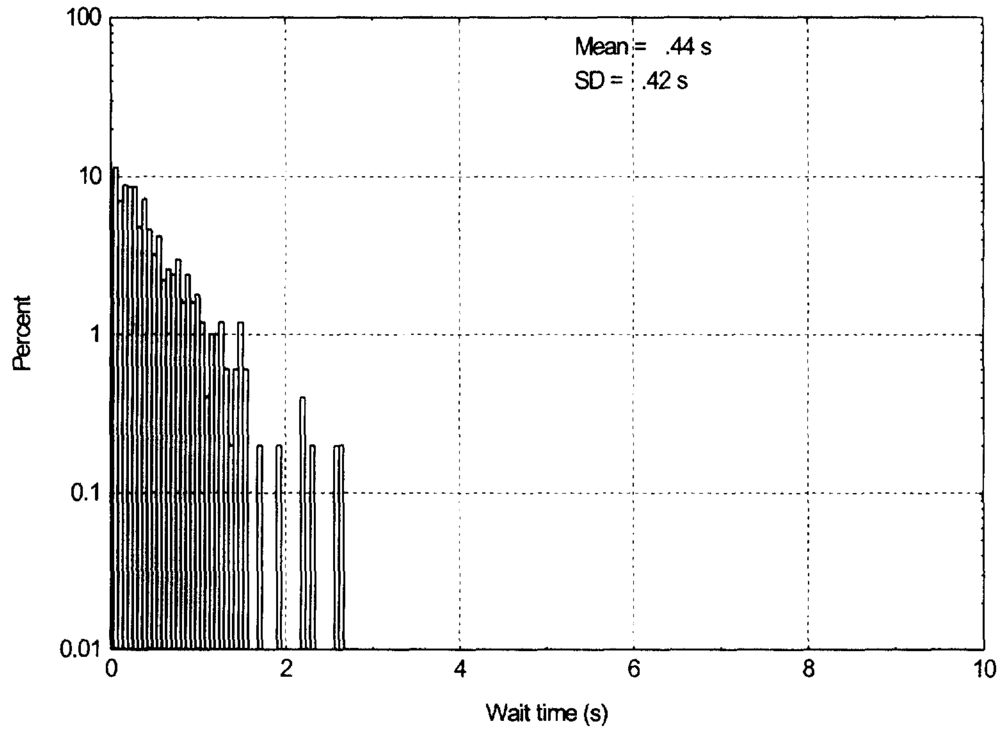

Figure A-5. Wait time histogram, interference pulse parameters: pulse width = 1 μs, pulse period = 1 ms, peak RF power = -48 dBm.

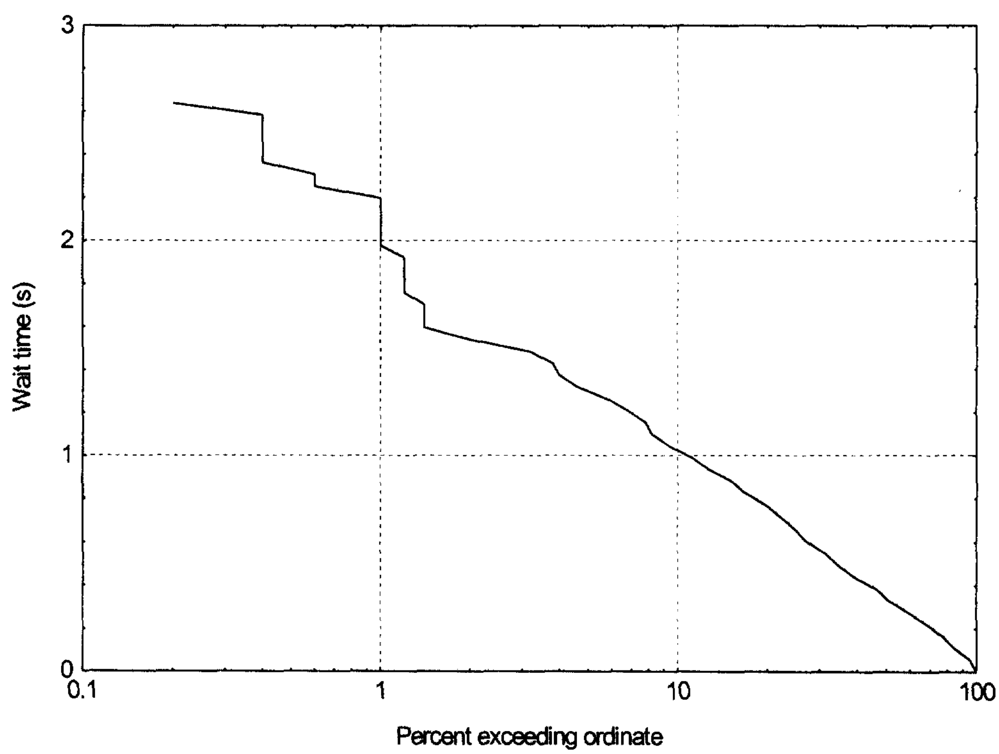

Figure A-6. Wait time cumulative distribution, pulse parameters: pulse width = 1 μs, pulse period = 1 ms, peak RF power = -48 dBm.

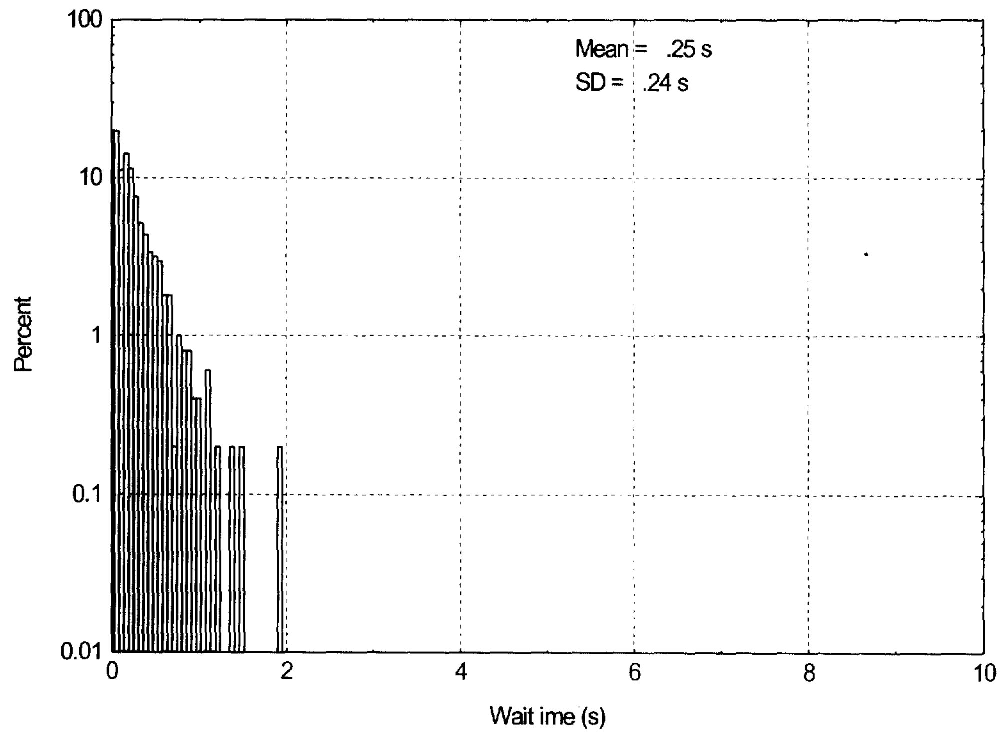

Figure A-7. Wait time histogram, interference pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = −89 dBm.

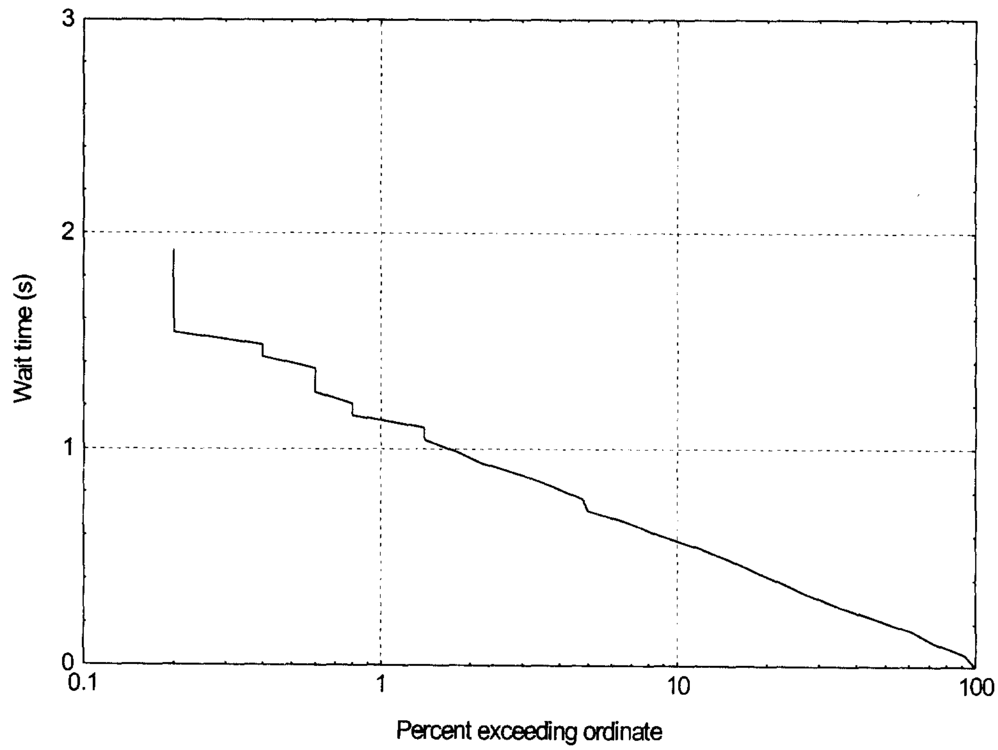

Figure A-8. Wait time cumulative distribution, pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = −89 dBm.

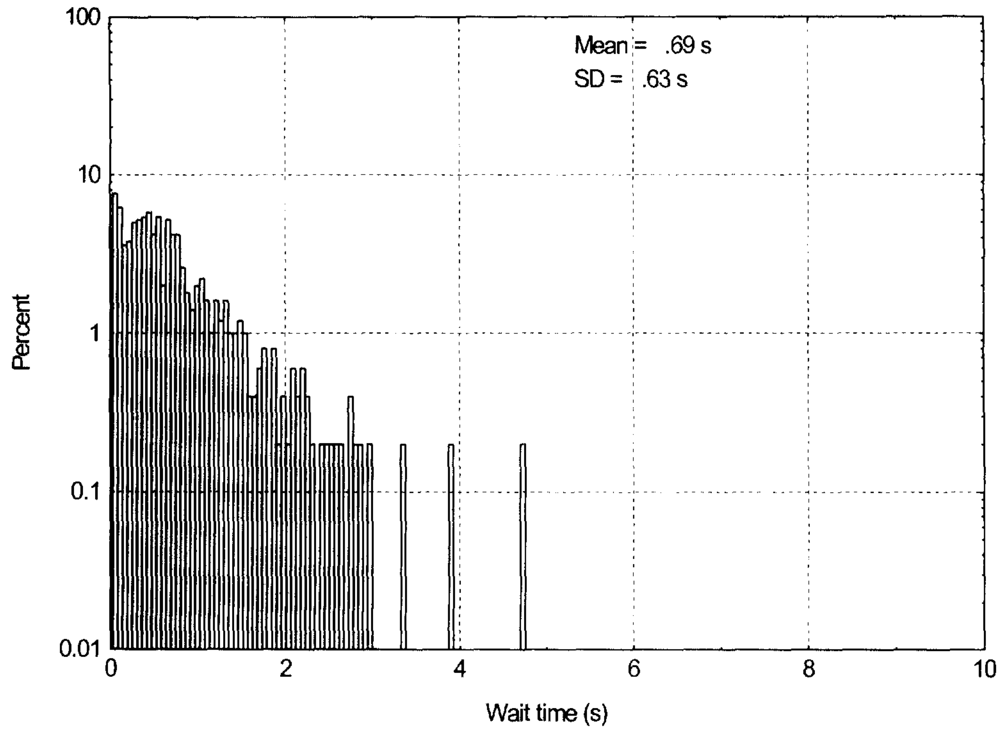

Figure A-9. Wait time histogram, interference pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = -79 dBm.

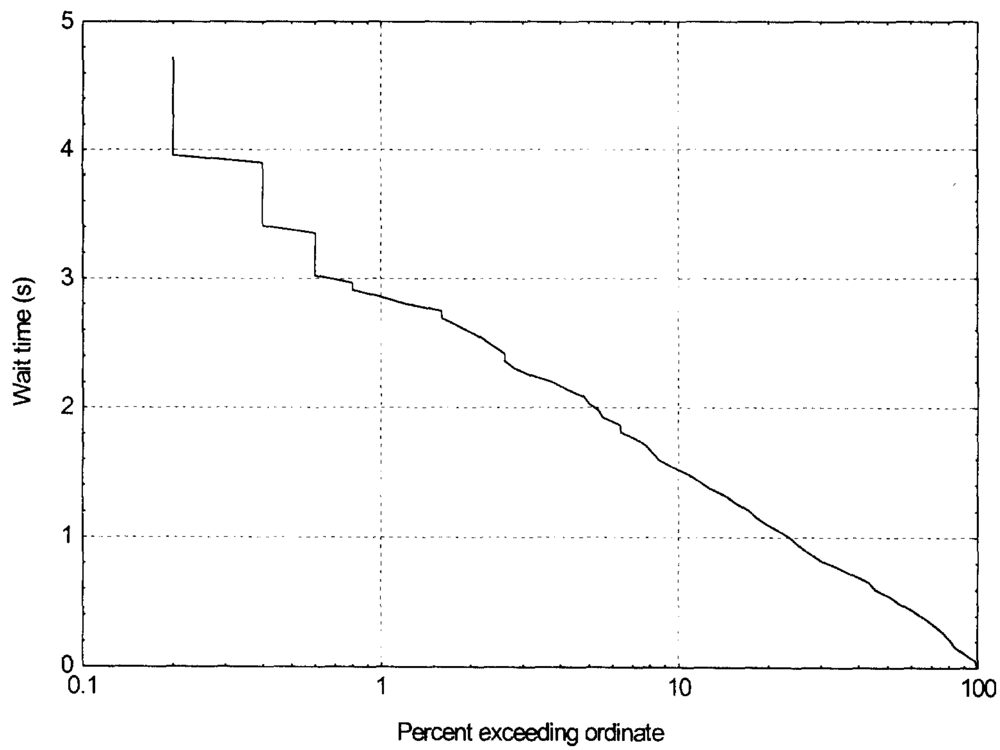

Figure A-10. Wait time cumulative distribution, pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = -79 dBm.

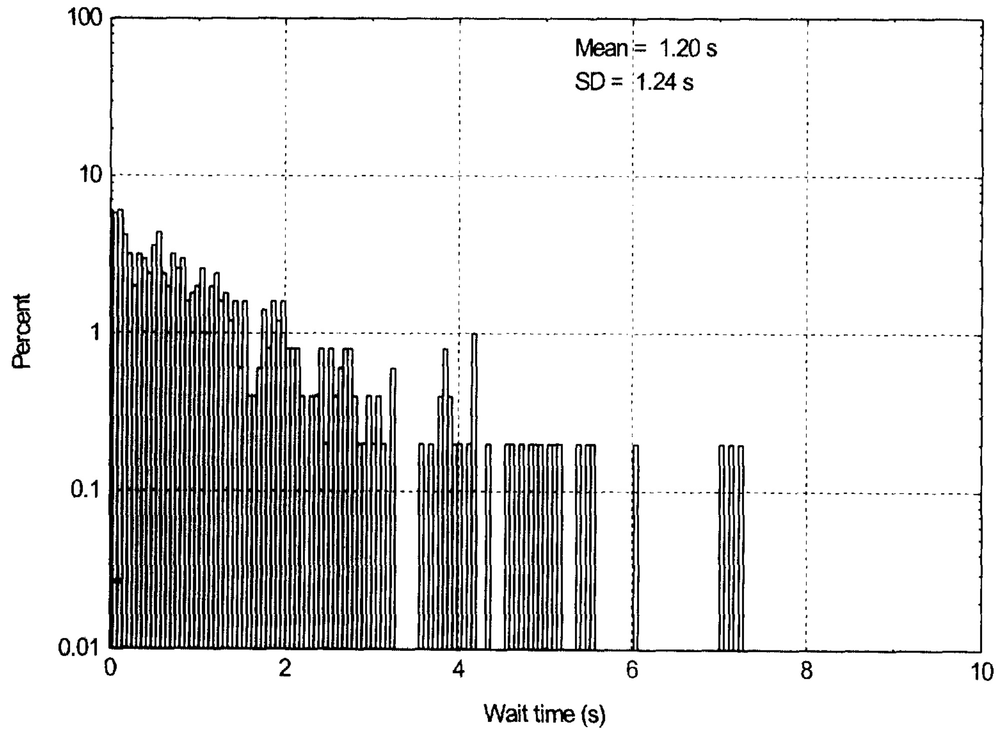

Figure A-11. Wait time histogram, interference pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = −69 dBm.

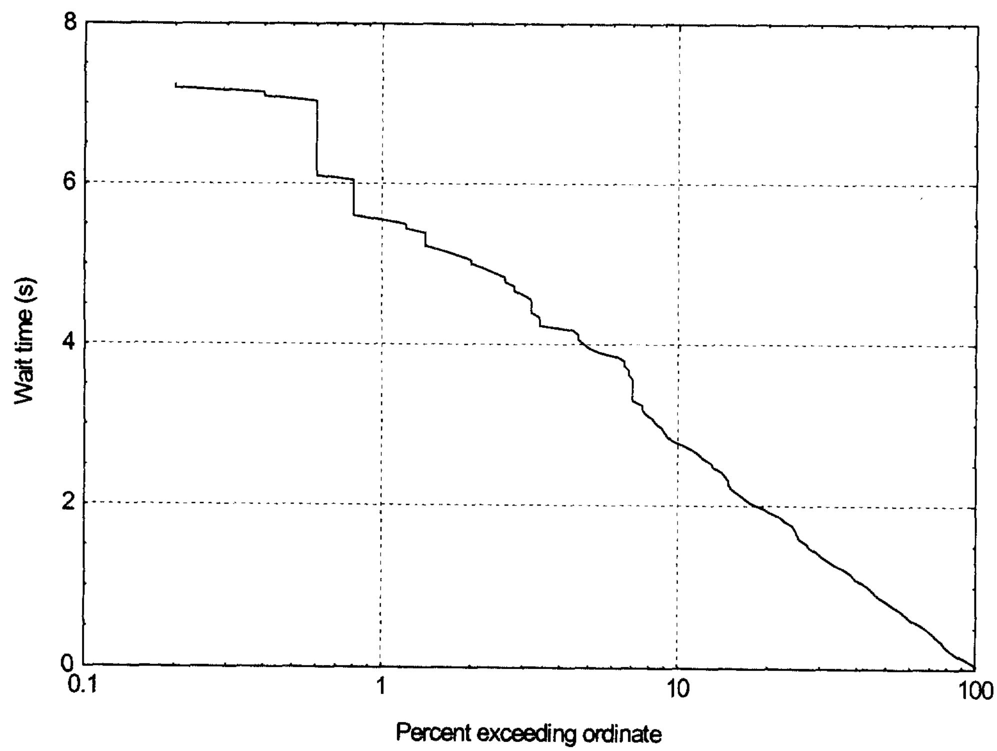

Figure A-12. Wait time cumulative distribution, pulse parameters: pulse width = 10μs, pulse period = 1 ms, peak RF power = −69 dBm.

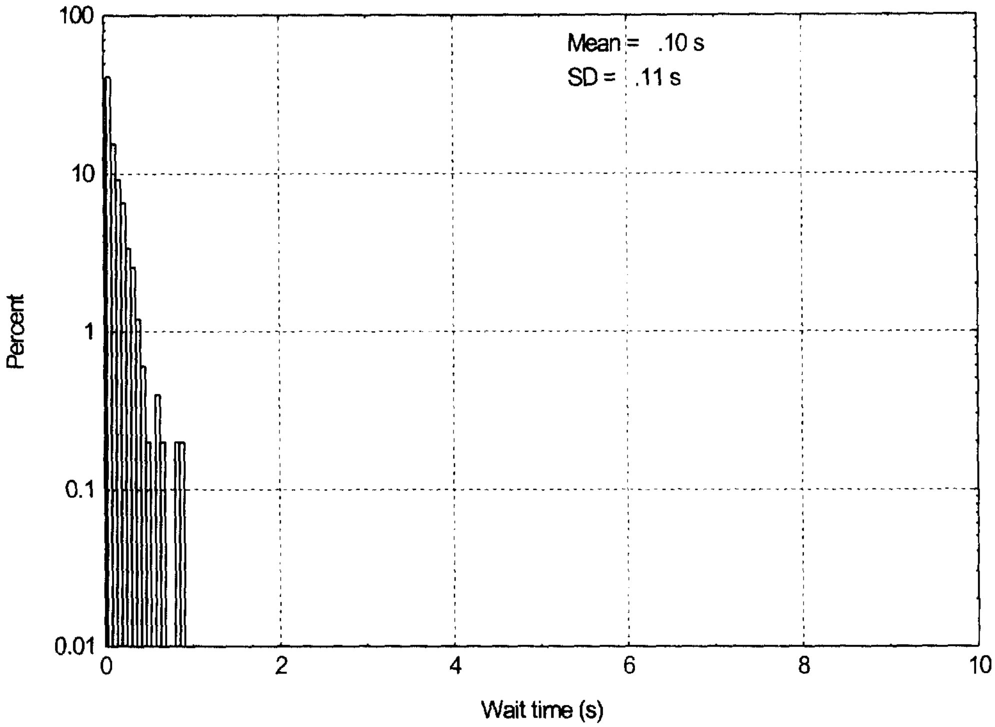

Figure A-13. Wait time histogram, interference pulse parameters: pulse width = 3.3 μs, pulse period = .330 ms, peak RF power = −91 dBm.

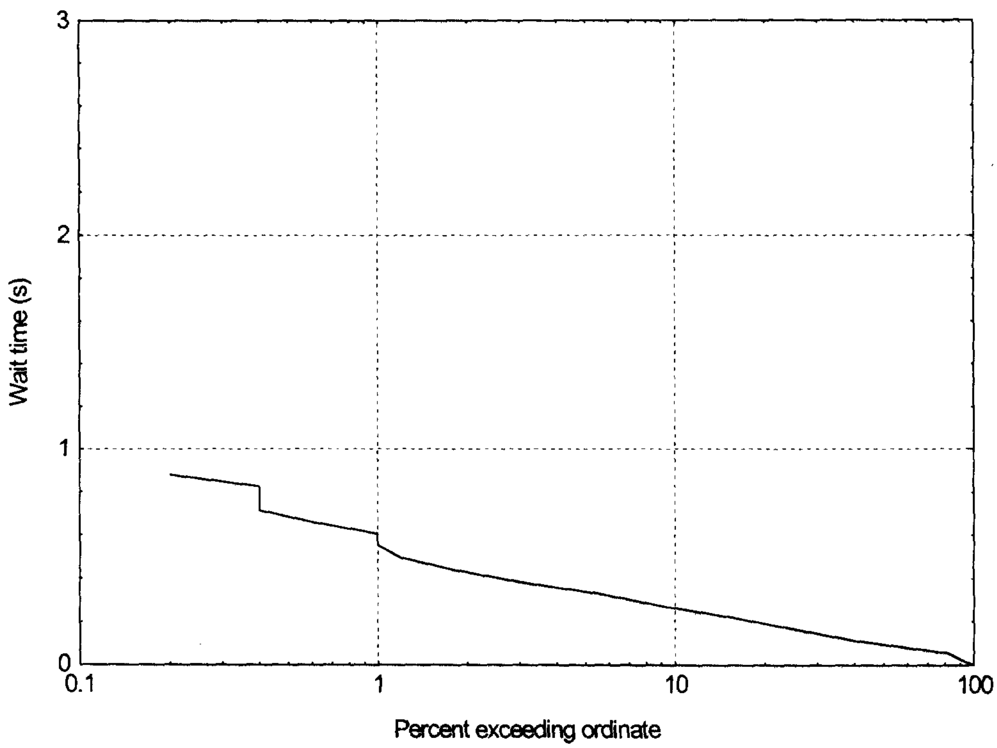

Figure A-14. Wait time cumulative distribution, pulse parameters: pulse width = 3.3 μs, pulse period = .330 ms, peak RF power = −91 dBm.

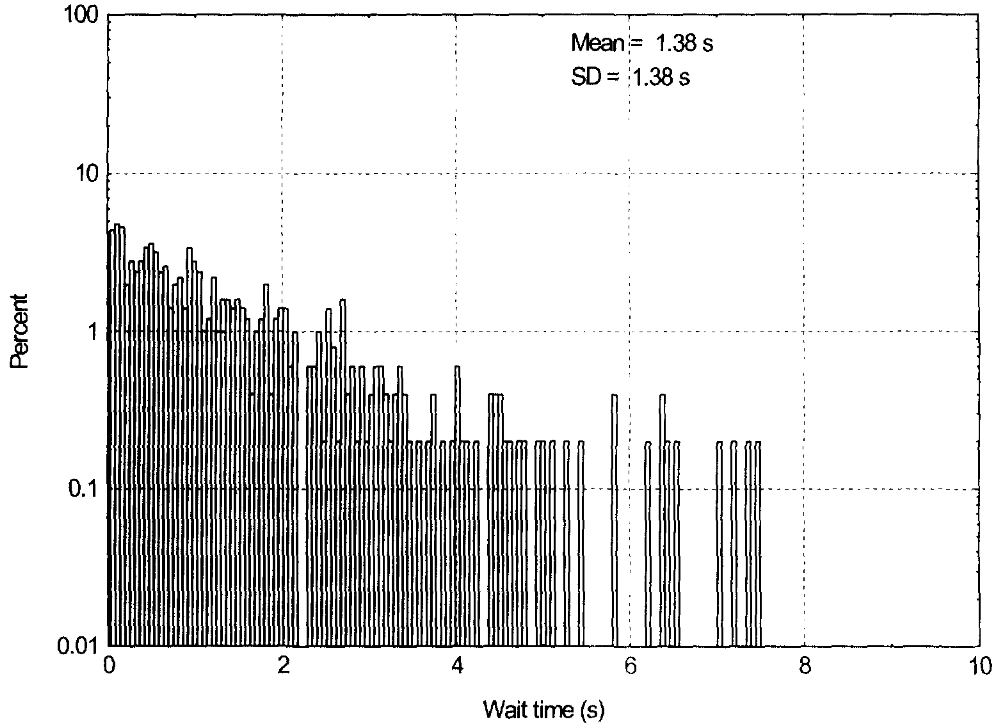

Figure A-15. Wait time histogram, interference pulse parameters: pulse width = 3.3 μs, pulse period = .330 ms, peak RF power = −81 dBm.

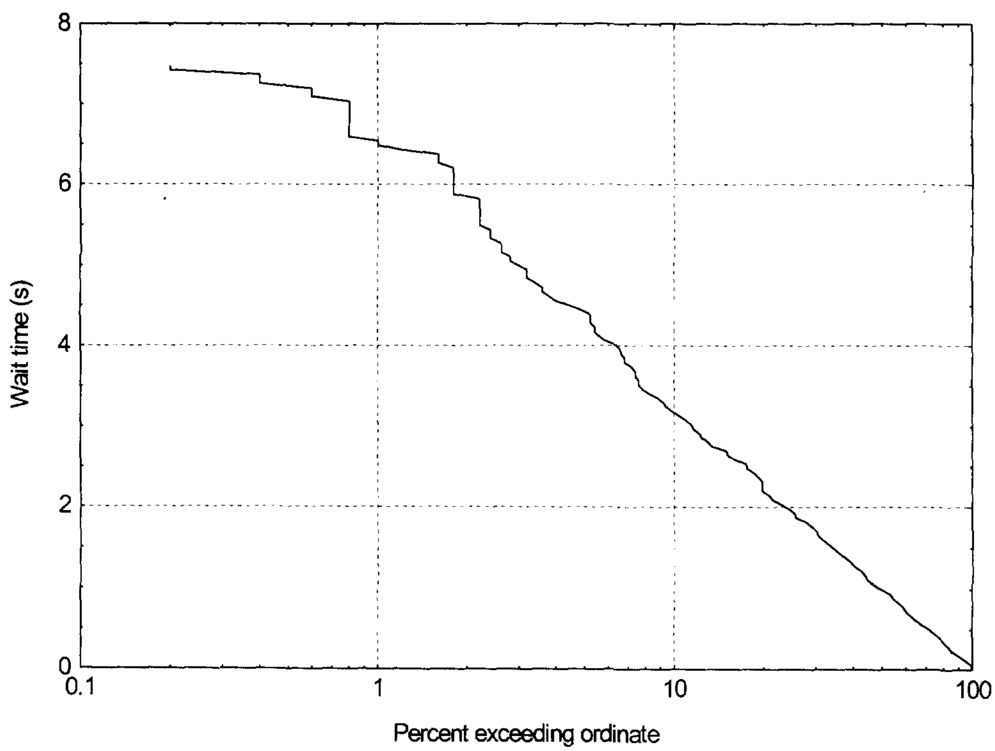

Figure A-16. Wait time cumulative distribution, pulse parameters: pulse width = 3.3 μs, pulse period = .330 ms, peak RF power = −81 dBm.

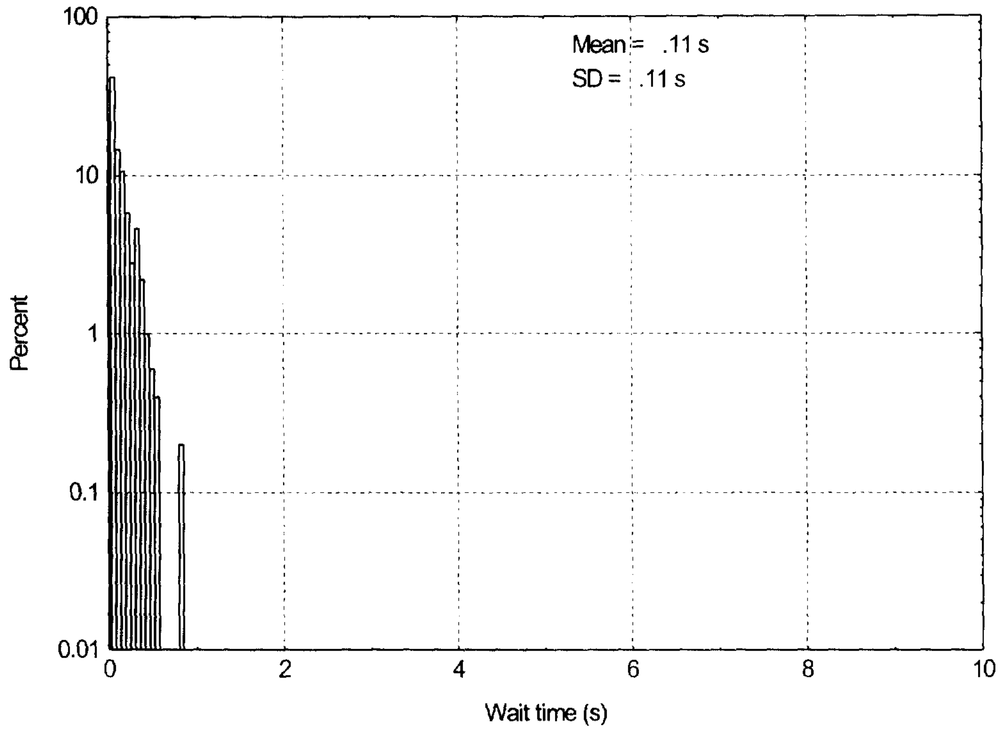

Figure A-17. Wait time histogram, interference pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = −71 dBm.

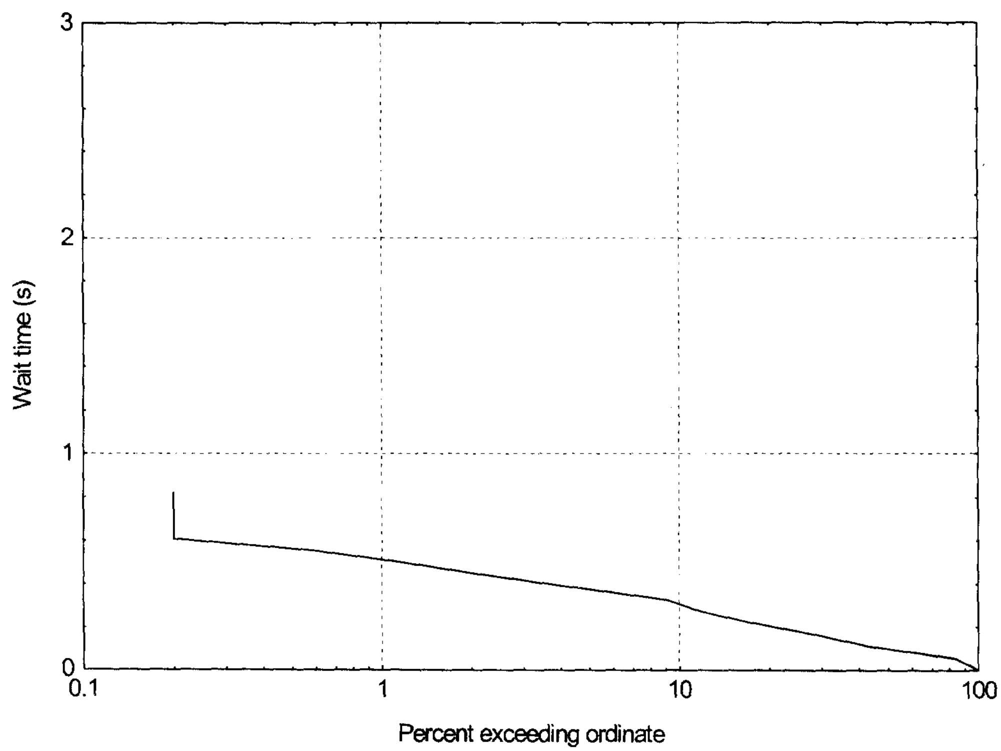

Figure A-18. Wait time cumulative distribution, pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = −71 dBm.

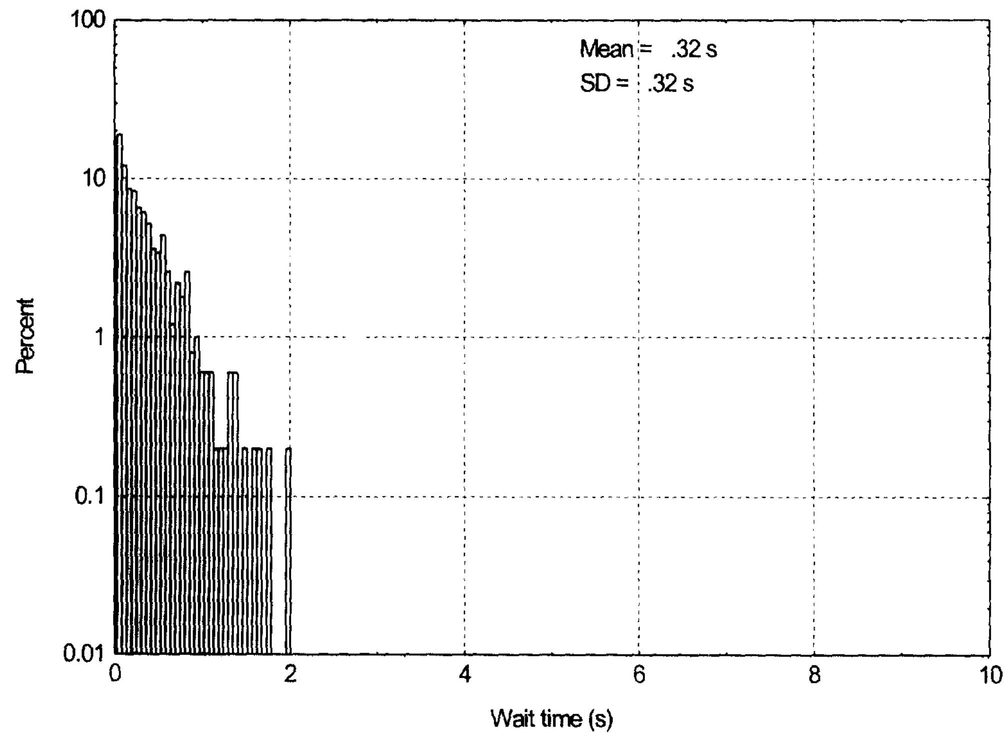

Figure A-19. Wait time histogram, interference pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = -61 dBm.

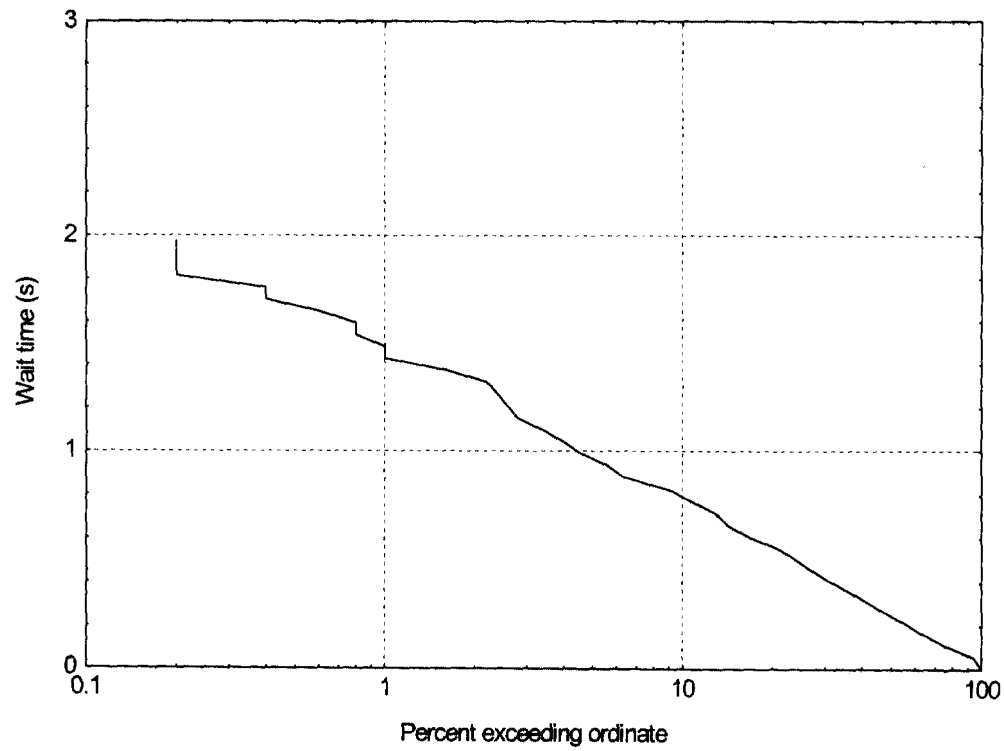

Figure A-20. Wait time cumulative distribution, pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = -61 dBm.

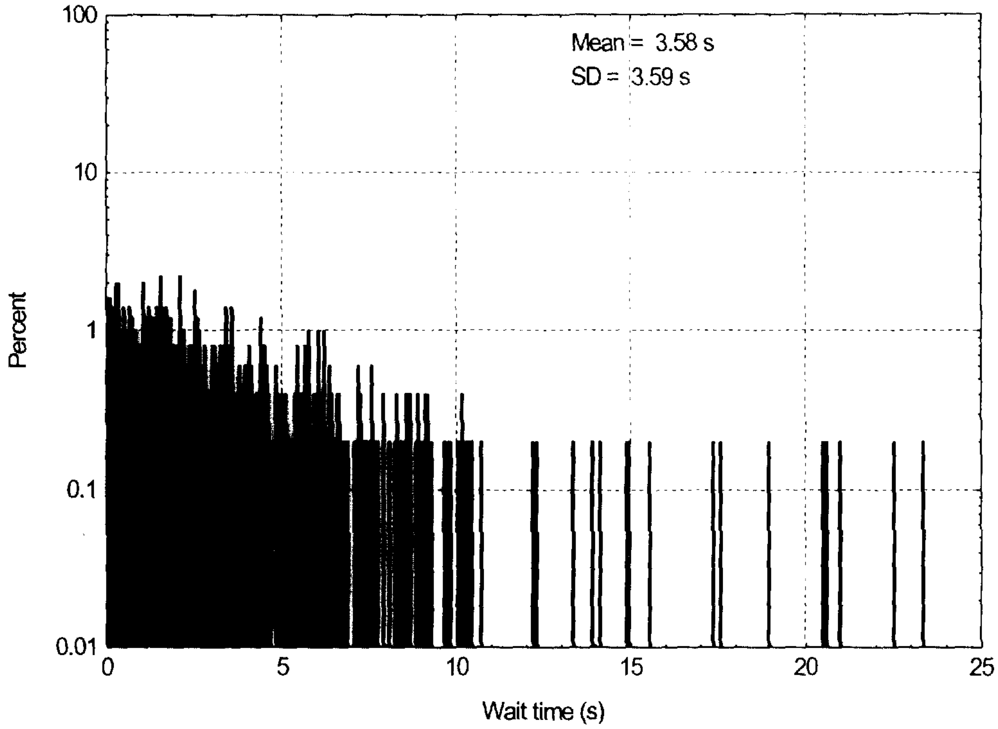

Figure A-21. Wait time histogram, interference pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = −51 dBm.

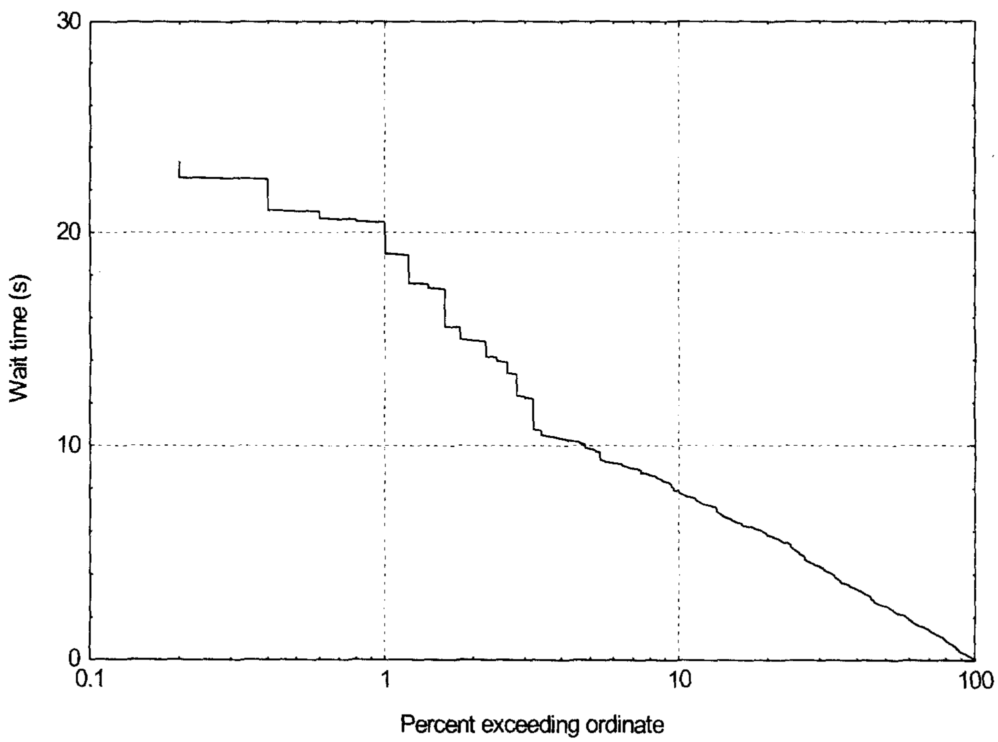

Figure A-22. Wait time cumulative distribution, pulse parameters: pulse width = .33 μs, pulse period = .330 ms, peak RF power = −51 dBm.

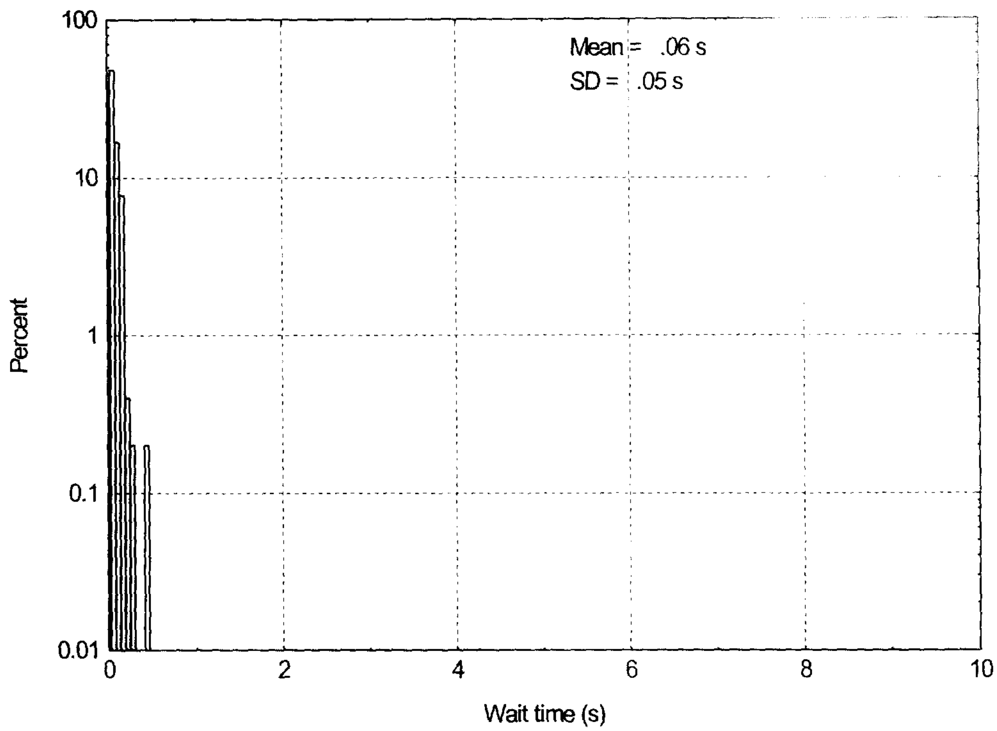

Figure A-23. Wait time histogram, interference pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = -24 dBm.

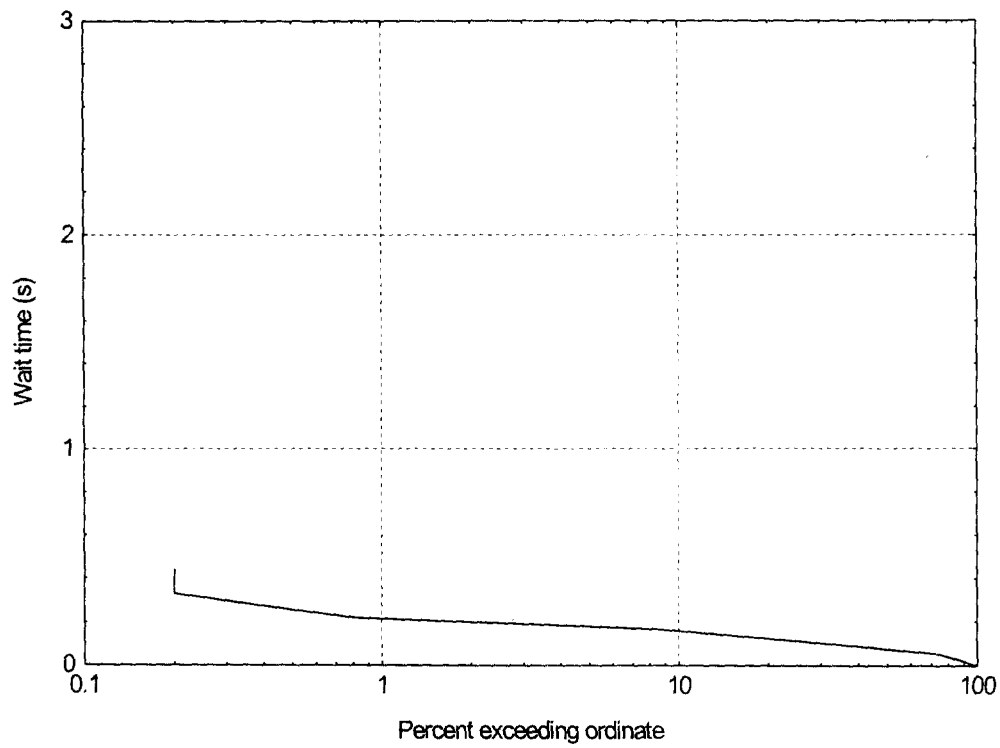

Figure A-24. Wait time cumulative distribution, pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = -24 dBm.

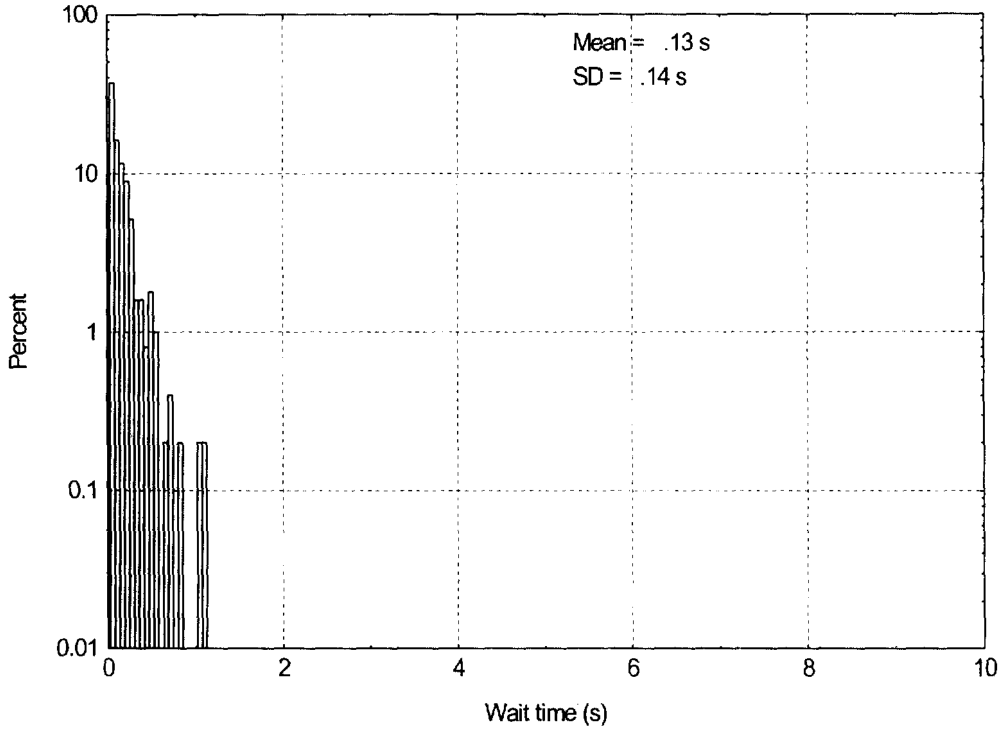

Figure A-25. Wait time histogram, interference pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = −14 dBm.

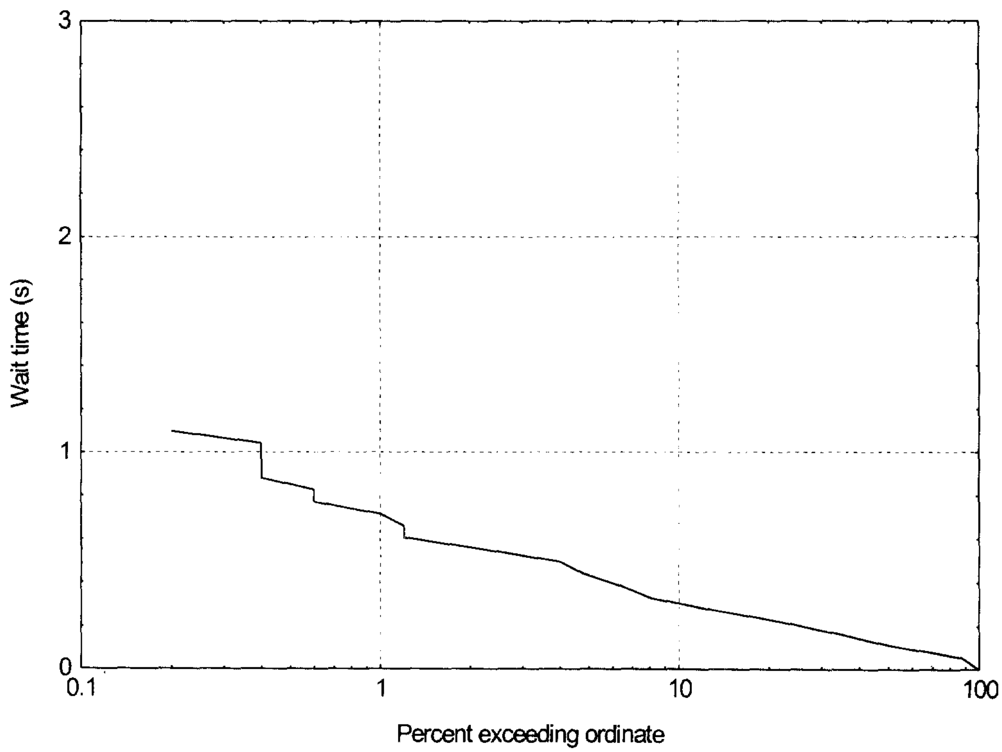

Figure A-26. Wait time cumulative distribution, pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = −14 dBm.

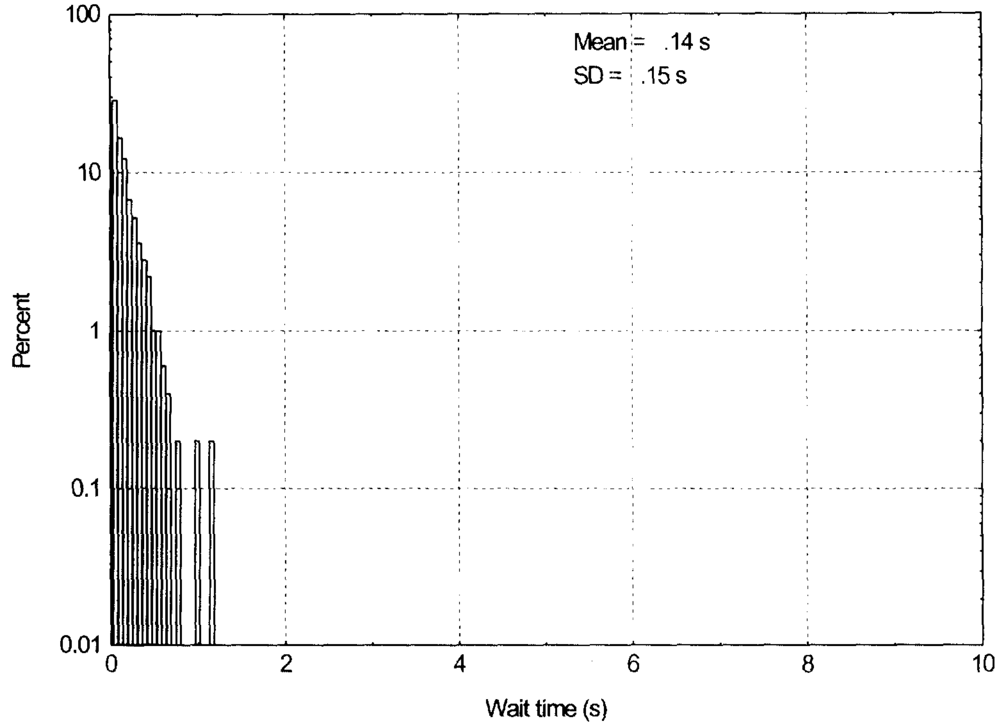

Figure A-27. Wait time histogram, interference pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = -4 dBm.

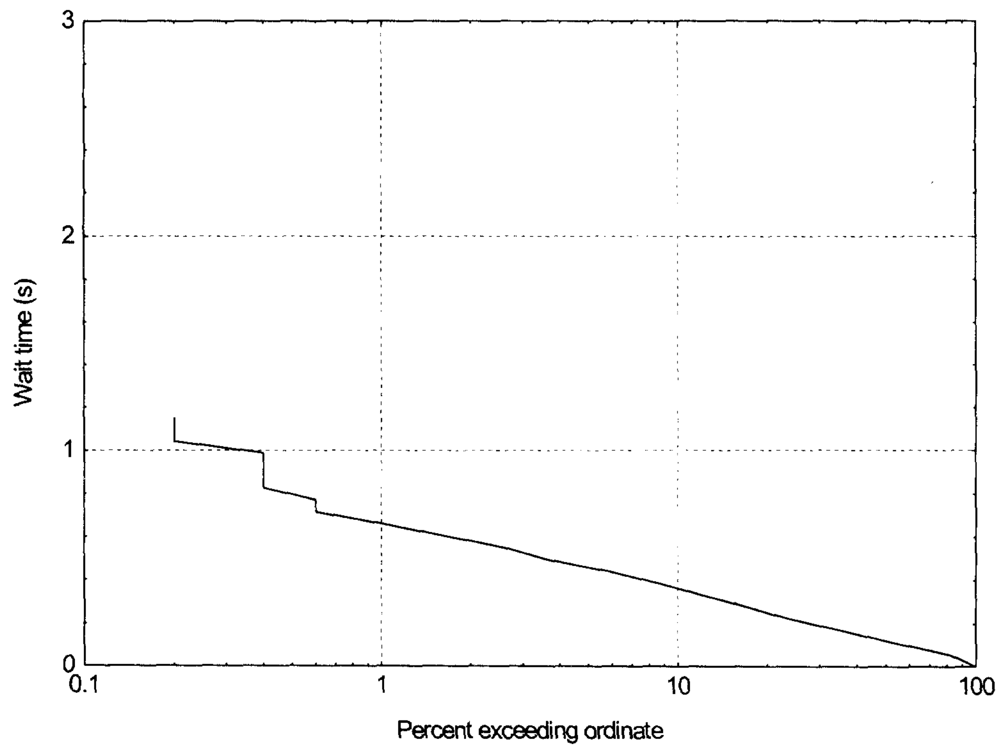

Figure A-28. Wait time cumulative distribution, pulse parameters: pulse width = 3.3 μs, pulse period = 3.3 ms, peak RF power = -4 dBm.

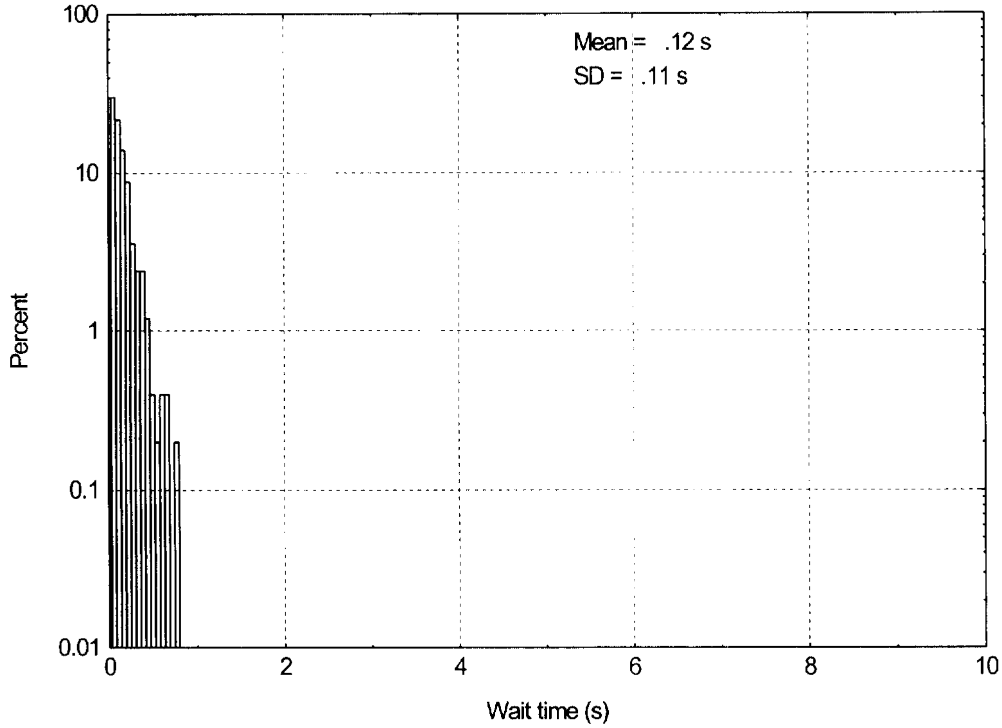

Figure A-29. Wait time histogram, interference pulse parameters: pulse width = .33 μs, pulse period = 3.3 ms, peak RF power = −21 dBm.

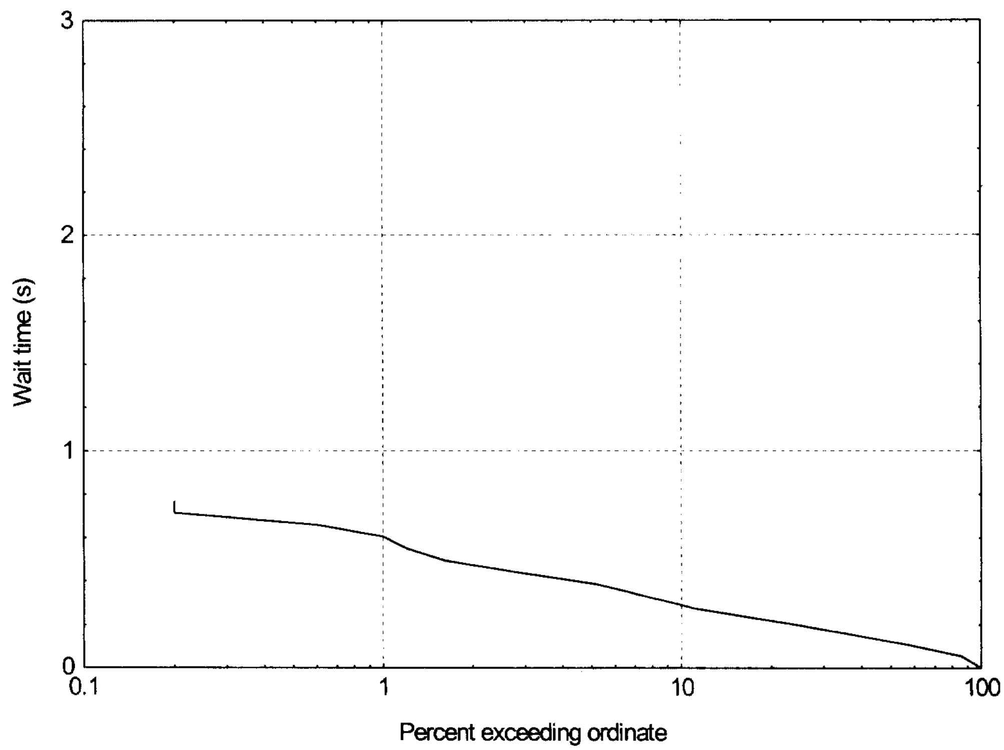

Figure A-30. Wait time cumulative distribution, pulse parameters: pulse width = .33 μs, pulse period = 3.3 ms, peak RF power = −21 dBm.

FORM NTIA-29
(4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.
98-352		

4. TITLE AND SUBTITLE
Electromagnetic Compatibility Testing of a Dedicated Short-range Communication System

5. Publication Date
July 1998

6. Performing Organization Code

7. AUTHOR(S)
Roger A. Dalke, Frank h. Sanders, Brent L. Bedford

8. PERFORMING ORGANIZATION NAME AND ADDRESS
NTIA/ITS.S
325 Broadway
Boulder, CO 80303-3328

9. Project/Task/Work Unit No.
910 6374

10. Contract/Grant No.

11. Sponsoring Organization Name and Address
NTIA
1401 Constitution Ave, NW
Washington, DC

12. Type of Report and Period Covered

13.

14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Dedicated short-range communication systems have been proposed for operation at locations across the United States in the 5850- to 5925-MHz band. Various search and tracking high-power radars operate at or near this frequency band and are a source of potential interference. The successful operation of such digital communication systems is dependent upon compatible operation and coexistence with these radars. The Institute for Telecommunication Sciences has performed a series of interference tests to determine the electromagnetic compatibility of DSRC systems used for automatic toll collection and high-power 5-GHz radars. The methods used to perform the tests and results are presented in this report.

16. Key Words *(Alphabetical order, separated by semicolons)*

access control systems; electromagnetic compatibility; electronic toll collection; dedicated short-range communications (DSRC) systems; high-power radars; interference

17. AVAILABILITY STATEMENT

- [X] UNLIMITED.
- [ ] FOR OFFICIAL DISTRIBUTION.

18. Security Class. *(This report)*	20. Number of pages
	43
19. Security Class. *(This page)*	**21. Price:**

NTIA FORMAL PUBLICATION SERIES

NTIA CONTRACTOR REPORT

Information generated under an NTIA contract or grant and considered an important contribution to existing knowledge.

NTIA HANDBOOK

Information pertaining to technical procedures, reference and data guides, and formal user's manuals that are expected to be pertinent for a long time.

NTIA MONOGRAPH

A scholarly, professionally oriented publication dealing with state-of-the-art research or an authoritative treatment of a broad area. A monograph is expected to have a long lifespan.

NTIA REPORT

Important contributions to existing knowledge but of less breadth than a monograph, such as results of completed projects and major activities, specific major accomplishments, or NTIA-coordinated activities.

NTIA RESTRICTED REPORT

Contributions that fit the NTIA Report classification but that are limited in distribution because of national security classification or Departmental constraints. This material receives full review and quality control equivalent to the open-literature report series.

NTIA SPECIAL PUBLICATION

Information derived from or of value to NTIA activities such as conference proceedings, bibliographies, selected speeches, course and instructional materials, and directories.

SPONSOR-ISSUED REPORTS

NTIA authors occasionally produce reports issued under an other-agency sponsor's cover. These reports generally embody the criteria of the NTIA Report series.

For information about NTIA publications, contact the ITS Technical Publications Office at 325 Broadway, Boulder, CO, 80303 Tel. (303) 497-3572 or e-mail shaw@its.bldrdoc.gov.

This report is for sale by the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, Tel. (703) 487-4650.

ATTACHMENT 3

Technical Standards

General. The Commission has here proposed only those rules necessary to prevent harmful interference among the licensees of DSRC systems and incumbent radio services with equal or greater allocation status. NPRM at 16. The Department agrees wholeheartedly with this approach. Many of the remaining technical criteria can and will be the subject of an ongoing standards development program supported by DOT and industry. In our opinion, this will strike the optimum balance between the ability to adopt standards early in the development of 5.9 GHz DSRC devices and the need for nationwide (and potentially worldwide) compatibility.

The standards development process for the band now used for DSRC services (902-928 MHz) began several years ago and progress has been difficult, due in part to the established markets of many companies and the existing infrastructure of many deploying organizations. Consensus has now been reached on most of the contentious issues in that band. This development, and the relatively small investment that industry and deploying organizations have made for services in the 5.9 GHz band, bode well for more prompt agreement on standards in that band. These factors also allow maximum flexibility to accommodate applications that have not yet been considered.

Power. Establishment of a maximum power limit (in terms of Effective Isotropic Radiated Power or "EIRP") is essential to ensure compatibility of the proposed and established uses of this band. Most DSRC applications will be low power and certainly fall well within the 30 W EIRP suggested by the Commission. However, it is important to remember that DSRC applications at the 5.9 GHz band will have greater flexibility and offer more services than currently available in the 902-928 MHz band. DOT can therefore envision several applications that may warrant higher EIRP. (One such application may use backscatter technology for certain in-vehicle signing/messaging applications.) Appropriate flexibility must be available for DSRC to be useful, while too much flexibility may cause undo interference to incumbents. The Department cannot recommend a specific power level, but anticipates that there will be comments from industry on this point. Additionally, DOT, while not ruling out wide-area applications, considers such applications unlikely at 5.9 GHz. It has been our assumption that DSRC devices would be "focused" into small areas rather than serve a wide area communication function. (Current manufacturers of 902-928 MHz DSRC equipment occasionally use the term "wide area" to imply "open road" operations, as opposed to the traditional "toll booth"-centered arrangements familiar to most travelers. The Department supports the development of "open road" applications, for these tend to have less of an adverse impact on overall traffic flow than do toll booth-type operations.

Emission Limits. The FCC has proposed to minimize interference by adopting emission limits that mirror those now in place for DSRC services (*i.e.*, LMS) in the 902-928 MHz band. The Department is concerned that a wholesale application of these emissions mask requirements may be too restrictive for the 5.850-5.925 MHz band. To achieve a similar emissions mask may increase the cost of DSRC devices sufficiently to hinder user acceptance. Although DOT has no specific recommendation for an emissions mask, we intend to examine the suggestions of other parties in this proceeding, and to offer in our reply comments an analysis of any technical criteria that are put forward.

RF Guidelines. The Commission has proposed to require that DSRC equipment meet existing RF safety guidelines. NPRM at 19. We consider this sufficient to ensure that the traveling public will not be exposed to excessive RF energy.

Channelization. The Commission has made a preliminary decision to defer adoption of a channelization plan, and instead to begin collecting information and analysis. NPRM at 21-22. Such a plan is important to national compatibility and must be decided early in the development of 5.9 GHz DSRC services. DOT considers that the FCC's approach provides an appropriate basis to encourage adoption of a channelization plan within a reasonable time frame. It is worth noting, however, that the reduction in frequency agility that is imposed by a rigid channel plan may suggest a different course.

It may be preferable, for example, simply to set carrier frequencies on integer 1 MHz multiples and allow channel assignments to be made on the basis of local interference conditions.

The Commission also seeks comment on the use of active and passive backscatter tags to communicate with roadside beacons, noting that the former are more spectrally efficient than the latter. NPRM at 20-22. The Department believes that each has its place within the panoply of DSRC operations. It is important to understand that passive backscatter technology allows a greater number of roadside beacons to operate than do active tags. This is based on the direction of transmission. Tags operating in a backscatter mode are energized by RF energy directed at the roadway and simply reflect a modified signal back to the roadside unit. Active tags receive the signal from a roadside unit and transmit back towards that unit at a higher power than backscatter systems. Thus, from the perspective of some incumbent users in this band, such as Fixed Satellite Service operators, it would be more advantageous to use backscatter technology whenever possible. The lower cost of passive backscatter technology, its superior frequency agility, and its greater reuse distance are also legitimate considerations. [1]

At the same time, there are advantages to active tags. They are capable of operating at greater distances, and in some safety applications (such as where users do not want to be near the vehicle) this greater range is very important. Additionally, as the Commission points out, there are some high data rate applications that would be more appropriately handled by an active, narrowband system. NPRM at 21. From this it appears that there is sufficient need for a system mix of both active and passive backscatter tags, and various channelization plans have been proposed that support both.

Reuse distances for backscatter systems will generally be larger than for active systems, until the beacon EIRP (which is adjusted to meet range requirements) is reduced to approach that of active system tags. At that point and below, the reuse distance is larger for active systems, since the tag EIRP is not variable. For this reason, very short-range applications can be more densely deployed if backscatter technology is employed.

---

[1]/ The reuse distance for passive systems would be on the order of 200 meters versus 100 meters for active systems.

Hence, a system mix of active and backscatter tags that meets many requirements would appear to be the best solution.

Finally, there are likely to be applications of DSRC that are not safety-related and could fall under Part 15 rules. It is the safety-related applications that need protection. Other applications, such as parking management, would not necessarily require protection since they are unlikely to be employed as safety-related services.